Fiber Testing and OTDR Basics

Brett Isley
Territory Sales Manager
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Complete Life Cycle Solutions
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Fiber Optic Basics
Optical Test Terminology

- Optical Return Loss (ORL)
- Optical Loss Budget
- Reflectance
- Index of Refraction (IOR)
- Pulse Width
- Insertion Loss (IL)
- Attenuation
- Macrobends
- Gainers
- Distance Scale
- Launch Conditions
- Backscatter
Principles of Light

- Light is electromagnetic energy that travels through air at approx. 300,000 km/s (c)
- Light is typically described by wavelengths (λ)
- Shorter wavelengths experience greater loss than longer wavelengths

![Graph showing light waves and wavelengths](image)

- 1310 nm
- 850 nm
- 1550 nm
Refraction

› Bending of light as it passes from one material to another
› Every material has a refractive index or index of refraction (IOR)
› Refractive index (n) is the ratio of the velocity of light in a vacuum to the velocity of light in a material.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Velocity of Light mps</th>
<th>Velocity of Light kps</th>
<th>Refractive Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space</td>
<td>186,282</td>
<td>299,792</td>
<td>1.00</td>
</tr>
<tr>
<td>Air</td>
<td>186,232</td>
<td>299,890</td>
<td>1.00</td>
</tr>
<tr>
<td>Water</td>
<td>140,061</td>
<td>225,442</td>
<td>1.33</td>
</tr>
<tr>
<td>Glass</td>
<td>122,554</td>
<td>197,349</td>
<td>1.52</td>
</tr>
<tr>
<td>Diamond</td>
<td>77,056</td>
<td>124,083</td>
<td>2.42</td>
</tr>
</tbody>
</table>

Refractive Index of Diamond = \frac{\text{speed of light in air medium}}{\text{speed of light in diamond}} = \frac{300000}{124120} = 2.417
Light travels through the core of a fiber (high index of refraction) by constantly reflecting away from the cladding (lower index of refraction). 

Fiber optic transmission uses total internal reflection to efficiently transmit light.
Attenuation

- Decrease in average optical power from the transmitter to the receiver

- Attenuation results from:
  1. Fiber Absorption/Scattering
  2. Connectors (.3 -.5dB ea)
  3. Fusion Splices (0.1dB ea)
  4. Macrobends

Link loss is the main performance limitation in a fiber. Determines the maximum distance between a transmitter and a receiver.

- Loss budget attenuation
  - Fiber Loss is wavelength-dependent
    1. 1310nm – .35db/km
    2. 1550nm – .22db/km
Bending Loss

- wavelength dependent
- increases as the wavelength increases.
- macrobends affect longer wavelengths more than shorter wavelengths.
Loss and Power measurement units

**dB or dBm…What is the difference?**

- **dBm = absolute power**
- **dB = power ratio**

<table>
<thead>
<tr>
<th>Power (dBm)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30 dBm</td>
<td>0.0000010 W</td>
</tr>
<tr>
<td>-20 dBm</td>
<td>0.0000100 W</td>
</tr>
<tr>
<td>-10 dBm</td>
<td>0.0001000 W</td>
</tr>
<tr>
<td>0 dBm</td>
<td>0.0010000 W</td>
</tr>
<tr>
<td>1 dBm</td>
<td>0.0012589 W</td>
</tr>
<tr>
<td>2 dBm</td>
<td>0.0015849 W</td>
</tr>
<tr>
<td>3 dBm</td>
<td>0.0019953 W</td>
</tr>
<tr>
<td>4 dBm</td>
<td>0.0025119 W</td>
</tr>
<tr>
<td>5 dBm</td>
<td>0.0031628 W</td>
</tr>
<tr>
<td>6 dBm</td>
<td>0.0039811 W</td>
</tr>
<tr>
<td>7 dBm</td>
<td>0.0050119 W</td>
</tr>
<tr>
<td>8 dBm</td>
<td>0.0063096 W</td>
</tr>
<tr>
<td>9 dBm</td>
<td>0.0079433 W</td>
</tr>
<tr>
<td>10 dBm</td>
<td>0.0100000 W</td>
</tr>
<tr>
<td>20 dBm</td>
<td>0.1000000 W</td>
</tr>
<tr>
<td>30 dBm</td>
<td>1.0000000 W</td>
</tr>
<tr>
<td>40 dBm</td>
<td>10.0000000 W</td>
</tr>
<tr>
<td>50 dBm</td>
<td>100.0000000 W</td>
</tr>
</tbody>
</table>

- **dBm = absolute power**
- **dB = power ratio**

1. When validating the loss budget **always** use dB
2. When validating receive level **always** use dBm

<table>
<thead>
<tr>
<th>Loss dB</th>
<th>Power Remaining %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0.2</td>
<td>95.5</td>
</tr>
<tr>
<td>0.4</td>
<td>91.2</td>
</tr>
<tr>
<td>0.6</td>
<td>87.7</td>
</tr>
<tr>
<td>0.8</td>
<td>83.2</td>
</tr>
<tr>
<td>1</td>
<td>79.4</td>
</tr>
<tr>
<td>2</td>
<td>63.1</td>
</tr>
<tr>
<td>3</td>
<td>50.1</td>
</tr>
<tr>
<td>4</td>
<td>39.8</td>
</tr>
<tr>
<td>5</td>
<td>31.6</td>
</tr>
<tr>
<td>6</td>
<td>25.1</td>
</tr>
<tr>
<td>7</td>
<td>19.9</td>
</tr>
<tr>
<td>8</td>
<td>15.8</td>
</tr>
<tr>
<td>9</td>
<td>12.6</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>0.1</td>
</tr>
<tr>
<td>40</td>
<td>0.01</td>
</tr>
<tr>
<td>50</td>
<td>0.001</td>
</tr>
</tbody>
</table>

3dB of loss = 50% of power lost!
Loss Budget – An engineering calculation of the expected fiber span loss. Includes all components in-line with the fiber

- *During Design*: ensures cabling will work with the links that will be used.
- *During Installation*: ensures plant has been installed properly.

### Sample Link Loss Budget Calculation

- **Fiber attenuation @ 1550nm = 0.22 dB/km**
  
  \[0.22 \text{ dB} \times 100 \text{ km} = 22 \text{ dB}\]

- **Splice loss average is 0.1 dB**

  \[0.1 \text{ dB} \times 12 \text{ splices} = 1.2 \text{ dB}\]

- **Connector loss average is 0.5 dB**

  \[0.5 \text{ dB} \times 2 \text{ connections} = 1.0 \text{ dB}\]

- **Design margin of error is 2 dB**

  \[1 \times 2\text{dB} = 2.0 \text{ dB}\]

**TOTAL LOSS BUDGET**: 26.2 dB
Reflections

Fresnel reflection is due to the light reflecting off a boundary of two optical mediums, each having a different refractive indexes (IOR).

Common sources of reflections are:

- Open fiber ends
- Cracks
- Mechanical Splices
- Connectors
Connectors: UPC vs. APC

**UPC**
- Insertion loss: <0.5 dB
- Reflectance: <-55 dB
- Real World: ~ -40 dB
- End of fiber: ~ -14 dB

**APC**
- Insertion loss: <0.5 dB
- Reflectance: <-65 dB
- Real World: ~ -50 dB
- End of fiber: ~ -60 dB
Optical Return Loss (ORL)

-30 dBm

• **End-to-End Loss** = Power Transmitted (dBm) – Power Received (dBm)
  - Power Tx = 0 dBm, Power Rx = -12 dBm
  - End-to-end loss = 0 dBm – (-12 dBm) = 12 dB

• **ORL** = Power Transmitted (dBm) – Power Returned to Transmitter (dBm)
  - Power Tx = 0 dBm, Power Returned to Tx = -30 dBm
  - ORL = 0 dBm – (-30 dBm) = 30 dB

Typical ORL Thresholds
1GE = 26 dB  
10GE = 29 dB  
100GE = 31 dB  
PON = 32 dB
Fiber Characterization

› What is it? A suite of tests used to qualify fiber end-to-end.
› Why? To characterize a fiber’s suitability for high-speed transport

› What are the Tests?
  › Insertion Loss (IL)
  › Optical Return Loss (ORL)
  › OTDR
  › *Chromatic Dispersion
  › *Polarization Mode Dispersion

› What are the Measurements?
  › End-to-end span loss
  › Span Length
  › Splice Loss
  › Connector Loss and Reflectance
  › Section Loss
  › ORL
  › *CD and PMD
Fiber Characterization Tools

Inspection scope: fiber connector health

OTDR: length, loss, ORL, event characterization, fiber map

OLTS: length, loss, ORL

VFL: continuity to 5km
OTDR – A tool of choice, WHY?

It reveals what?

<table>
<thead>
<tr>
<th>Total Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical return Loss</td>
</tr>
<tr>
<td>Fiber Length</td>
</tr>
</tbody>
</table>

It is used for what?

<table>
<thead>
<tr>
<th>Characterize link components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map link components</td>
</tr>
<tr>
<td>Locate a fault</td>
</tr>
</tbody>
</table>
OTDRs launch a series of pulses into optical fiber and plot the energy level and round-trip time of all reflections to create a trace. The round-trip time is converted to distance on the trace.
Two types of reflection:

1- Rayleigh Backscattering

- Results from natural reflection of the fiber
- The OTDR uses backscatter to measure fiber attenuation (dB/Km)
- Back reflection level around -75 dB
- Shorter wavelengths = more backscatter = steeper attenuation slope
Two types of reflection:

1- Fresnel back reflections

- Caused by abrupt changes in the IOR (glass/air): fiber break, mechanical splice, connectors
- Reflections will be approximately 20 000 times higher than fiber’s backscattering level
- Displayed as a “spike” on the OTDR trace
Set up on the OTDR can affect the credibility of the trace. The 3 basic settings are:

- **Distance**
- **Pulse**
- **Acquisition Time**
OTDR Distance Range

- Scales the graph
- Controls pulse repetition rate
- Sets dynamic range
- Set to at least 1.5x distance
OTDR Averaging Time

- Controls time to acquire trace
- Longer averaging time can reduce trace noise
OTDR Pulse Width

- Greatest affect on performance
- Affects distance and resolution

- 5 ns = 1.6 feet
- 100 ns = 33 feet
- 20 microseconds = 1.3 miles
Event dead zone

- The minimum distance between the beginning of a reflective event for detecting a second reflective event

It is the distance between:

- Event beginning
- -1.5 dB point on trailing edge
Attenuation dead zone

- The minimum distance needed after a reflective event in order to perform a loss measurement.

It is the distance between:

- Beginning of event
- Point on trailing edge where receiver detects ±0.5 dB from normal backscatter level
## Typical Dead Zone by Pulse Width

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Dead zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 nsec</td>
<td>1 m</td>
</tr>
<tr>
<td>30 nsec</td>
<td>3 m</td>
</tr>
<tr>
<td>100 nsec</td>
<td>10 m</td>
</tr>
<tr>
<td>275 nsec</td>
<td>27.5 m</td>
</tr>
<tr>
<td>1 usec</td>
<td>100 m</td>
</tr>
<tr>
<td>2.5 usec</td>
<td>250 m</td>
</tr>
<tr>
<td>10 usec</td>
<td>1 Km</td>
</tr>
<tr>
<td>20 usec</td>
<td>2 Km</td>
</tr>
<tr>
<td>Distance Tested (Km)</td>
<td>Pulse width / Acquisition time</td>
</tr>
<tr>
<td>----------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>&lt; 1.5</td>
<td>5 ns / 30 s or 10 ns / 15 s *</td>
</tr>
<tr>
<td>1.5 to 5</td>
<td>10 ns / 30 s or 30 ns / 15 s *</td>
</tr>
<tr>
<td>5 to 10</td>
<td>10 ns / 45 s or 30 ns / 30 s *</td>
</tr>
<tr>
<td>10 to 20</td>
<td>30 ns / 45 s or 100 ns / 30 s *</td>
</tr>
<tr>
<td>20 to 40</td>
<td>100 ns / 60 s or 275 ns / 45 s *</td>
</tr>
<tr>
<td>40 to 80</td>
<td>275 ns / 90 s or 1 us / 60 s *</td>
</tr>
<tr>
<td>80 to 120</td>
<td>1 us / 90 s or 2.5 us / 60 s *</td>
</tr>
<tr>
<td>120 to 160</td>
<td>2.5 us / 120 s or 10 us / 90 s *</td>
</tr>
<tr>
<td>160 to 200</td>
<td>10 us / 120 s or 20 us / 90 s *</td>
</tr>
<tr>
<td>200 to 260</td>
<td>20 us / 120 s *</td>
</tr>
</tbody>
</table>

All configurations depend on the OTDR model used
* depends on resolution needed
Auto Mode

› All OTDRs have an “AUTO Mode”
› Purpose of AUTO Mode is to choose the best settings to reach the end of fiber
› These settings may not provide the best analysis of the fiber overall
› If an accurate fiber map is desired it is best to acquire more than one trace using different distance and pulse width settings
› Begin with AUTO, choose settings for the middle of the fiber, then finish with shortest settings
› A trace from other end may be needed for closely spaced events at end of the fiber
Trace Analysis
### Event Table

<table>
<thead>
<tr>
<th>Type</th>
<th>Icon representation of event type</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>Event number or span between events</td>
</tr>
<tr>
<td>Loc.</td>
<td>Distance from event</td>
</tr>
<tr>
<td>Loss</td>
<td>Loss of event</td>
</tr>
<tr>
<td>Refl</td>
<td>Reflectance of event</td>
</tr>
<tr>
<td>Cumul.</td>
<td>Total loss</td>
</tr>
</tbody>
</table>

The event table is worth a thousand words.

#### Event icons displayed in the Event table

<table>
<thead>
<tr>
<th>Icon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>🔄</td>
<td>Positive end</td>
</tr>
<tr>
<td>🔄</td>
<td>Launch level</td>
</tr>
<tr>
<td>🔄 Harbour</td>
<td>Fiber section</td>
</tr>
<tr>
<td>🔄 End of analysis</td>
<td>Merged reflective event</td>
</tr>
<tr>
<td>🔄 Non-reflective event</td>
<td>Reflex</td>
</tr>
<tr>
<td>🔄 Reflective event</td>
<td>Reflective event (possible echo)</td>
</tr>
</tbody>
</table>
Macrobend

- 1310 nm: normal OTDR trace
- 1550 nm: huge event loss
- 1625 nm: end-of-link located at 8.7 kft
PON Splitters are displayed as high loss events

<table>
<thead>
<tr>
<th>Split ratio</th>
<th>1:2</th>
<th>1:4</th>
<th>1:8</th>
<th>1:16</th>
<th>1:32</th>
<th>1:64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss (dB)</td>
<td>3.3</td>
<td>6.6</td>
<td>9.9</td>
<td>13.2</td>
<td>16.5</td>
<td>19.8</td>
</tr>
</tbody>
</table>
Ghosting

- Ghosts are false reflections
- Caused by highly reflective events on fiber
- Appear at multiples of the fiber length
Gainers

- Mode field diameter = power per unit area = “light intensity”
- Smaller core size = greater intensity than larger core size
- Gainer caused by transition to smaller MFD
- Shows as a “step up” in trace
- Opposite direction trace will show loss
- Use bidirectional traces to average out

![Diagram showing splice loss and gainer](image)

```
Average Splice Loss = 0.45 + (-0.25) / 2 = 0.10
```
- Eliminates gainers by averaging gain and loss together
- Reveals events that are hidden by dead zones in one direction but not in the other
- Can highlight *0 dB events*, when a fiber splice shows neither a loss nor a gain on a single OTDR trace. In other words, as light crosses from one fiber to the next, the backscatter may increase just enough to compensate for the actual splice loss.
Out of Range

- Not enough dynamic range to complete trace
- Note noisy end of fiber and event table icon
- Repeat test with larger pulse width
Removing OTDR Complexity with iOLM

Traditional OTDR Trace
- Methodical approach and expertise required
- Multiple trace acquisitions commonly required
- Manual interpretation and diagnosis

iOLM
- Automated, dynamic multi-pulse acquisitions
- Results combined into a single linear view
- All analysis combined into one linear view
- Clear pass/fail and diagnosis
Specialized OTDRs
PON Optimized OTDR

Testing through PON splitters requires:

- High dynamic range
- Optimized pulse shaping and analysis algorithms
In-service Testing of PON requires

- Out of band wavelength: 1625nm (PON) or 1650nm (EPON)
- Filtered OTDR port to reject other wavelengths
- Testing wavelength routed networks requires specific wavelengths, CWDM or DWDM
- Ensures end-to-end continuity on a per wavelength basis
OTDRs by Distance

Fiber

Long Haul Network
Metropolitan Network Core
Metropolitan Network Edge

Copper / Coax

Local Access Network
Premises Network

CATV

cell site

FTTx
Cleaning & Inspection
Impact of Dirty Connectors

According to multiple surveys up to 90% of fiber issues involve dirty or damaged connectors.

As data rates increase the importance of connector health increases.
Examples

Wet Residue
After Drying

Oil Residue
Adhesive Defect

Scratches
Mated Wet
Residue Transfer

Residues can transfer and may create permanent damage when mating

Before mating:

After mating:

Patch Panel
Cleaning Methods

1. Dry method
   • Efficient for light contaminants
   • Fast and easy

2. Wet method
   • Raises contaminants to avoid scratching
   • Most commonly uses 99.9% isopropyl alcohol
   • Can leave residue

3. Combination method (hybrid)
   • Cleans all soil types
   • Reduces potential for static attraction
   • Dries moisture and solvent
   • Captures soil
## Analysis Software

### Zones

<table>
<thead>
<tr>
<th>Zones</th>
<th>Scratches</th>
<th>Defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Core (0-65 µm)</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>B: Cladding (65-120 µm)</td>
<td>No limit ≤3 µm None &gt;3 µm</td>
<td>No limit &lt;2 µm 5 from 2 – 5 µm None ≥5 µm</td>
</tr>
<tr>
<td>C: Adhesive (120-130 µm)</td>
<td>No limit</td>
<td>No limit</td>
</tr>
<tr>
<td>D: Contact (130-250 µm)</td>
<td>No limit</td>
<td>None ≥10 µm</td>
</tr>
</tbody>
</table>

![Image of ConnectorMax software interface](image.png)
Live Demo